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Phenomenology Research Using Past Nevada Test Site Explosion and Earthquake Data

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PHENOMENOLOGY RESEARCH USING PAST NEVADA TEST SITE EXPLOSION AND EARTHQUAKE DATA

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ABSTRACT

We use regional waveform data from the Nevada Test Site (NTS) to investigate phenomenological relationships between recorded amplitude and explosion yield as well as test regional depth estimation procedures. Our goal is to better understand the performance of seismic observables in other regions of monitoring interest, especially at small magnitudes (m_b<<4.5). Some of the topics we are studying include: stable yield estimation, depth estimation, and M_s:m_b performance. We use Lawrence Livermore National Laboratory's NTS explosion database, which consists of several hundred events ranging from ~200- to ~1500-m depth and yields ranging from a few tenths of a kiloton to the megaton range. In addition to the broadband explosion data, we have a large dataset of well-located earthquakes on the test site with depths ranging from 2 to 17 km and magnitudes ranging between M_W1.5 and 5.7.

For yield estimation the relation between teleseismic body wave magnitude (m_b) and nuclear explosion yield has been studied extensively over the past several decades for a number of test sites for large (>1 kt) explosions. In this paper we will look at broadband coda, P_g, and L_g from over 260 nuclear explosions to study yield estimation capability by comparing F-factors. For monitoring compliance with a CTBT, small events that are recorded only at regional distances will be used to estimate magnitude and equivalent yield. Past coda studies show that coda-derived magnitudes of earthquakes and explosions are more stable than any direct phase method, including $m_b(L_g)$. In fact, single-station coda measurements can be equivalent to a network average of at least ten direct phase measurements over a broad range of frequencies.

In regions where the depth estimate is poorly constrained, other regional methods have been proposed to estimate depth. These include time-domain measures of P-wave complexity, cepstral peaking, and more recently spectral peaking from R_g-to-S scattering. Myers et al. (1999) and Mayeda and Walter (1996) showed that strong spectral peaking in the S-wave and coda were likely due to R_g-to-S scattering in the near-source region. We propose a side-by-side comparison of these techniques in a region with excellent ground truth, namely NTS. We will investigate to what extent cepstral peaking, coda spectra peaking, and complexity provide a reliable depth estimate.

Finally, a number of large regional studies computing surface wave dispersion curves throughout the globe will be used to push the M_s measurements to smaller magnitude by the use of phase-matched filters. For larger teleseismically recorded events, we will test to see if the M_s:m_b trends for explosions and earthquakes continue to separate at small magnitudes at regional distances.

Although NTS is unique from other test sites in its geologic characteristics, this dataset of explosions and earthquakes is ideal for a number of reasons: (1) continuous recordings from high-quality broadband stations, (2) ground truth information that far exceeds any other area, (3) path and site effects that are virtually common for all events, and (4) wide range in depth, source size, and material properties. Because our goal is phenomenological in scope, we will use these results to guide our interpretations and assess our capability in other areas of monitoring interest.

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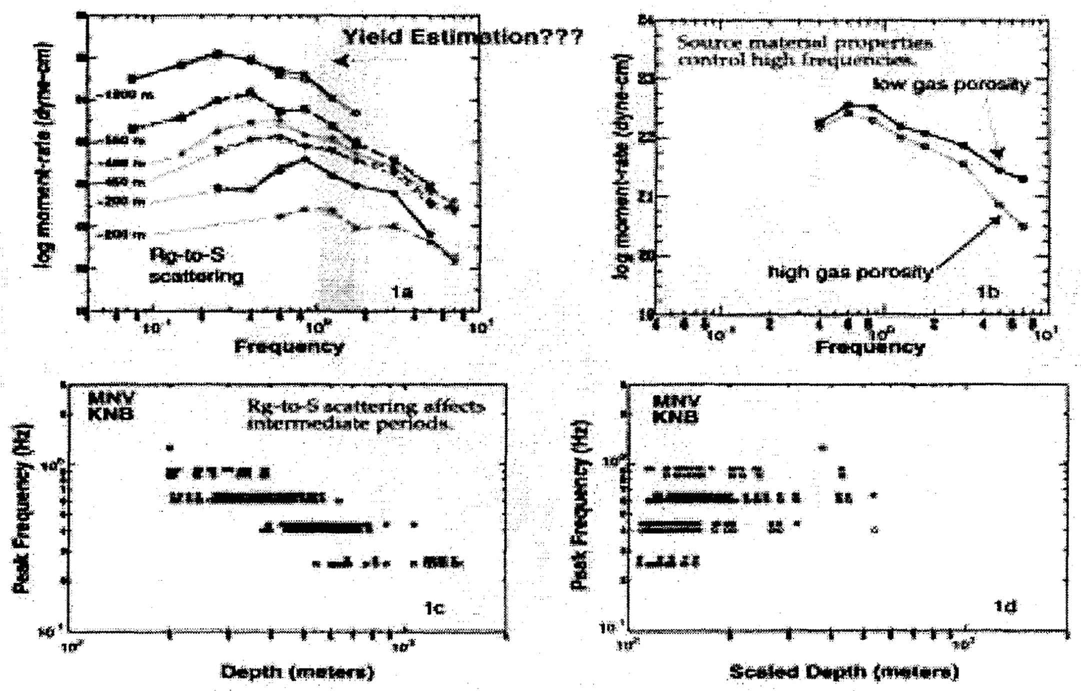
OBJECTIVE

We are in the process of testing a number of regional seismic techniques on ground-truth data from the Nevada Test Site in order to better understand how they will work in regions where we lack ground truth. For example, we have studied magnitude-yield relationships using the regional phases such as Pg, Lg and Lg coda for ~250 nuclear explosions over a broad range yield, depth, and source material property to ascertain the best measure for yield estimation. For large explosions recorded teleseismically the discriminant of choice is the Ms:mb discriminant but there have been very few regional studies to verify the continued separability at small magnitudes. Finally, because NTS has both shallow (<2 km) depth earthquakes and normal crustal depth earthquakes we are testing the cepstral techniques which claim depth estimation capability.

RESEARCH ACCOMPLISHED

Depth

Coda spectral peaking has been observed for NTS explosions (Figure 1a) as well as during the recent Depth-of-Burial explosions in Kazakhstan (Myers et al., 1999). We hypothesize that the spectral peaking is the result of depth-dependent excitation of Rg which scatters into S. To test this we plotted the location of the spectral peak versus the depth of burial and the scaled depth (depth/yield**0.333) in Figures 1c & 1d. We see that there is a good correspondence between peak frequency and depth of burial but not for scaled depth. Another test of our ground-truth data is to apply a cepstral peak algorithm to rigorously test the methodology.



We hypothesize that yield can be best estimated near 1 Hz, avoiding Rg-to-S scattering and source material effects.

Yield Estimation

We have measured Pg, Lg and coda amplitudes in multiple frequency bands (0.1<f<6.0 Hz) and plotted against official yield for roughly 250 nuclear explosions at NTS. Upon separating the populations into those fired in high-strength/low gas porosity material versus low strength/high gas porosity material, we found that in high-strength material the F-value using the coda at ~1 Hz was 1.80 whereas Pg and Lg were roughly 33% larger (Figure 2). For frequencies below ~1 Hz, spectral peaking related to Rg-to-S scattering caused an increase in the F-value and for high frequencies (f>~3 Hz) the source material effects strongly influenced the spectral decay (Figure 1b). We are now applying this technique to other IMS stations in the Middle East, former Soviet Union, and north Africa.

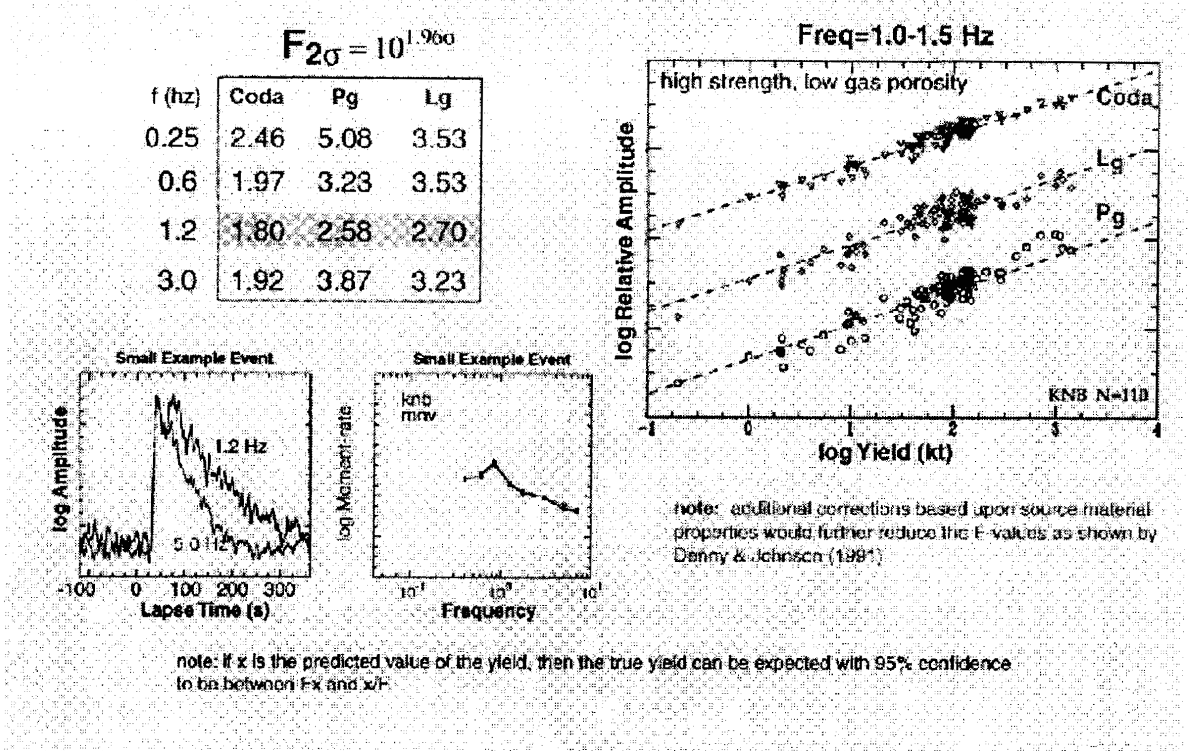


Figure 2. Coda amplitudes provide significantly better correlation with yield than direct regional phases for well-tamped events in high strength material.

Coda

Narrowband coda measurements have been shown to provide the most stable source size estimate of any of the regional phases. For small magnitude events the length of available coda will be small and eventually the coda measurement will be asymptotic to the direct S arrival. We are testing the interstation variance using two LLNL stations, KNB and MNV, for common events at NTS as a function of the coda window length. We hope to obtain a mapping of error versus window length so that in areas where we only have one coda measurement, we can place an error estimate.

Ms:mb

We are using large explosions recorded at LLNL's regional broadband stations to form match-filters to estimate Ms for the smaller explosions and earthquakes from the NTS region. Figure 3 shows the teleseismic Ms:mb separation works for events in the Middle East and North Africa region and it is our goal to test this at small magnitudes at regional distances for the Western United States. See also Pasyanos et al. in this session.

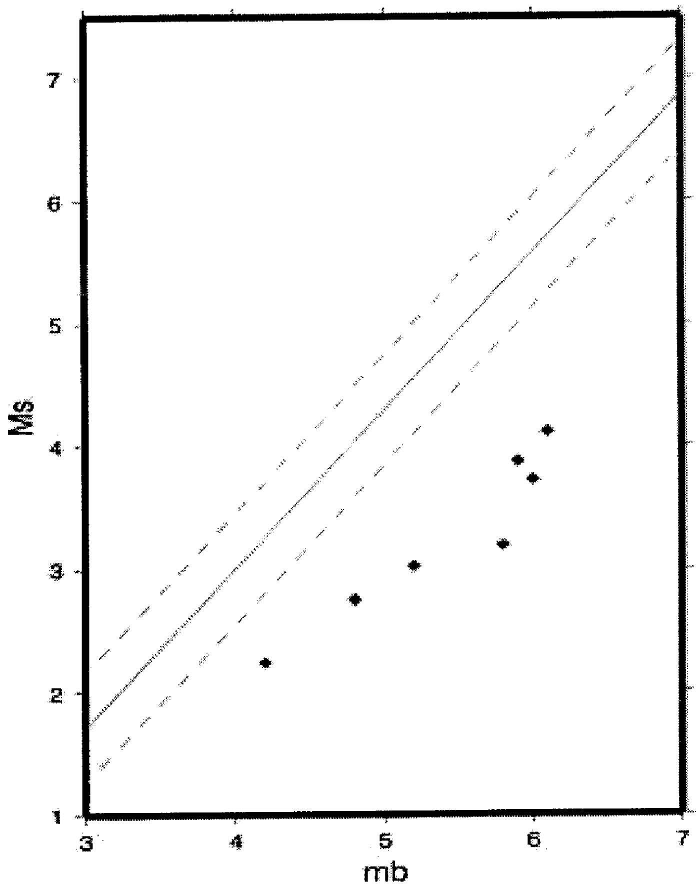


Figure 3. Plot of mb vs. Ms for events which have been phase-matched filtered using the group velocities predicted from the surface wave tomography. The best fitting regression of the earthquakes (not shown) and one standard deviation are shown by the solid and dashed green lines. Explosions are indicated by the red diamonds (see Pasyanos et al. this session).

CONCLUSIONS and RECOMMENDATIONS

The NTS dataset of explosions and earthquakes can guide us in the interpretation of regional seismic techniques in other regions where we lack ground truth data. We are extending the yield and Mw:mb studies to Borovoye Peaceful Nuclear Explosion (PNE) data as well as other regions of monitoring interest.

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